NOVEL MULTI-PURPOSE LIC'S INTRODUCE NEW CONCEPTS INTO CIRCUIT DESIGN*

by David Bingham

INTRODUCTION

The unique electrical and economical considerations governing the design of integrated circuits lead to new circuit approaches for consumer products. Although the complexity of an integrated circuit tends to limit the number of useful applications, it is still possible to design-in flexibility of circuit functions.

This paper describes several multi-purpose, dual-function LIC's (linear integrated circuits). A basic IC "chip" with a variety of interconnection patterns allows a choice of circuit functions. The IC's consist of two independent sections. These sections can be combinations of the following: (a) either a high-gain IF AGC amplifier, or an amplifier-limiter and FM quadrature detector; and (b) either an audio amplifier capable of driving an audio output transistor or tube, or an additional IF amplifier.

INTEGRATED CIRCUIT DESIGN CONSIDERATIONS

The primary cost of an integrated circuit is determined by the chip size, the number of external connections made to the chip, and the type of package. As the area of integrated components varies according to the type and value, it is important to choose circuit configurations that perform given functions with the minimum chip area. No longer does the cost of individual transistors or active amplifying devices restrict the circuit design. In fact, the use of a transistor is sometimes preferable to the use of other integrated components.

Figure 1 compares the approximate chip areas of various integrated components. It can be seen that large-value capacitors and resistors occupy greater areas than do transistors. Connection pads are also space-consuming and occupy about twice the area of a transistor. One of the most economical components fabricated in monolithic form is the emitter-follower NPN transistor. This component is therefore widely used in many linear microcircuits either as an impedance transformer or as a level shift or as both. If the emitter is biased positive with respect to the base, it can be used as a Zener diode. The area associated with an emitter-follower is small because it does not require a separate isolation area and, therefore, can be put into a common isolation

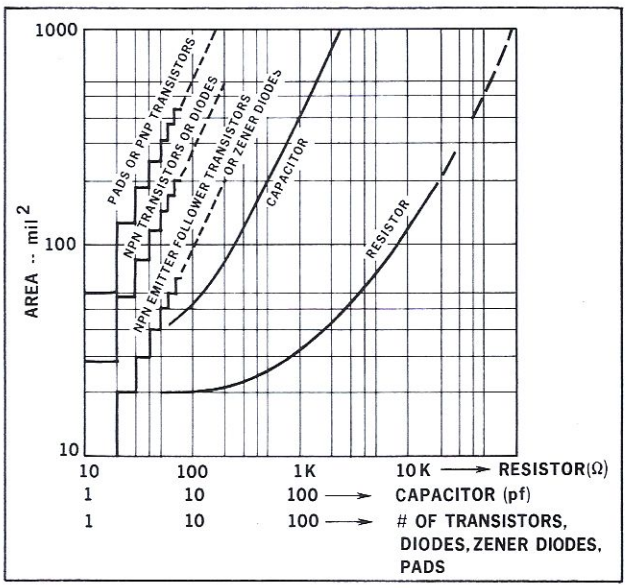

Fig. 1. Approximate chip area for various integrated components.

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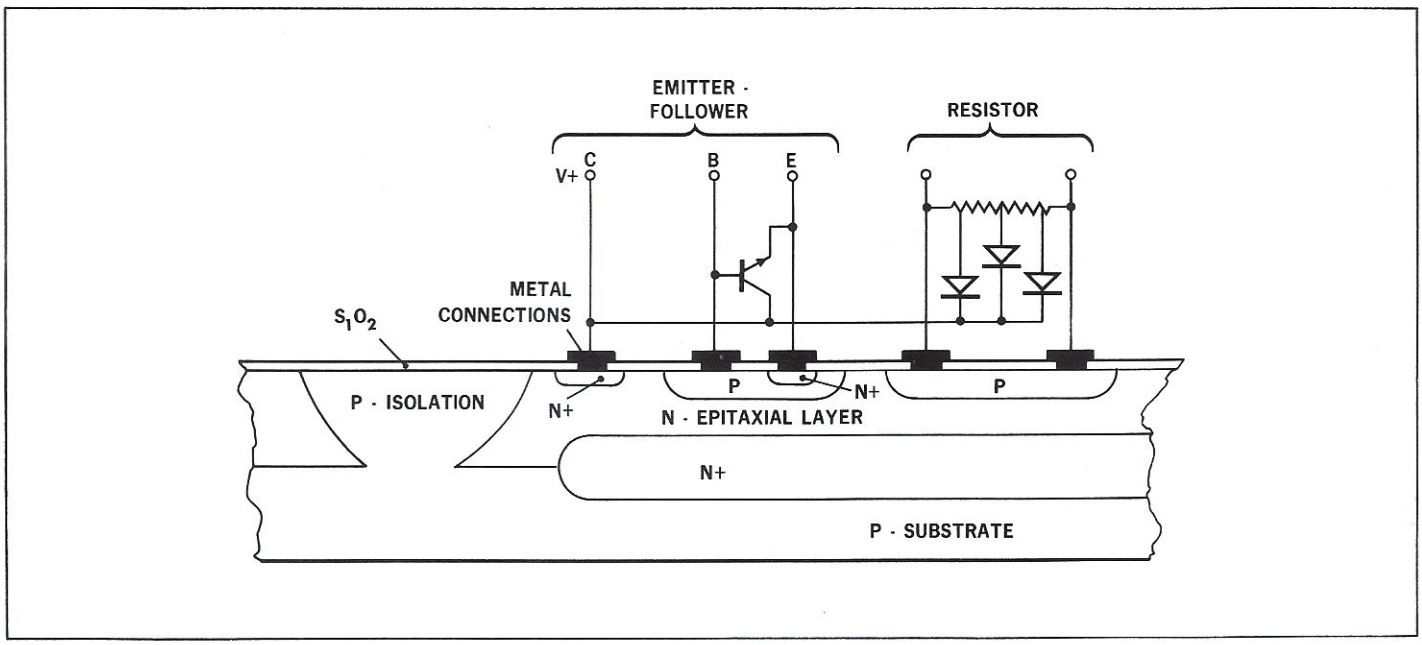

Fig. 2. Sectioned view of an IC chip showing an NPN emitter-follower transistor and a resistor.

area together with the resistors. In this normally large isolation area, the N-type epitaxial is electrically connected to the positive supply, which is AC grounded (Fig. 2). The P-type diffusions from which the resistors and bases of the NPN transistors are fabricated are at a lower potential than the N-type epitaxial region. Therefore, the junctions formed between the resistors and the bases of the emitter-follower and the epitaxial layer are reversed-biased.

The area taken up by the isolation diffusion separating regions of the chip can be large, therefore the number of these regions should be kept to a minimum. As a general rule, the area of a low-cost, consumer, linear microcircuit should not exceed 3000 square mils.

Another important consideration in the design of an integrated circuit is the close matching of similar components, whether they are transistors, diodes, resistors, or capacitors. As a guideline for consumer integrated circuits, the matching tolerances of similar components are: resistors ±4 per cent, capacitors ±10 per cent, transistor h_{FE} ±15 per cent, and V_{BE} ±5 millivolts. The absolute values for individual components from nominal values may be: resistors ±30 per cent, capacitors ±30 per cent, and transistor h_{FE} -50 per cent to +150 per cent.

From both area and component matching considerations, the differential pair or emitter-coupled pair is a useful integrated-circuit amplifying or switching building block. Only one isolation area is required in addition to the large isolation containing all the resistors and emitter-followers. As an IF or RF amplifier, the emitter-coupled pair offers high gain with good RF stability. As a switch, the pair offers high speed if used in the current mode operation, whereby neither transistor is allowed to saturate.

THE μA717, μA718, μA719, AND μA720.

A new series of multi-function linear integrated circuits, the μA717 through μA720, combine both the linear and the digital characteristics of emitter-coupled configurations to attain the following RF-IF functions:

1. A high-gain amplifier useful to 50 MHz with both current mode limiting and the AGC capability.
2. A high-gain amplifier with current mode limiting capability and a built-in FM quadrature detector useful from 1 to 20 megahertz.
3. A high-gain amplifier quadrature detector with the possible simultaneous use of the quadrature detector as an audio preamplifier for FM-AM applications.

In addition to the RF function, each microcircuit contains an additional amplifier for low-frequency audio preamplifier and driver applications.

CIRCUIT DESCRIPTION

RF Section

The high-frequency section of the μA717 through μA720 series of microcircuits is shown in Fig. 3. There are essentially three, cascaded, differential amplifiers, the third of which may be used as an FM quadrature detector by the addition of a quadrature tank circuit. Between the stages, RC-coupling was chosen instead of DC-coupling to allow the application of AGC to one stage only, and because it permitted more components of the quadrature detector to be contained on the chip, and thereby reduced the number of external connections to the chip as well as the number of external components.

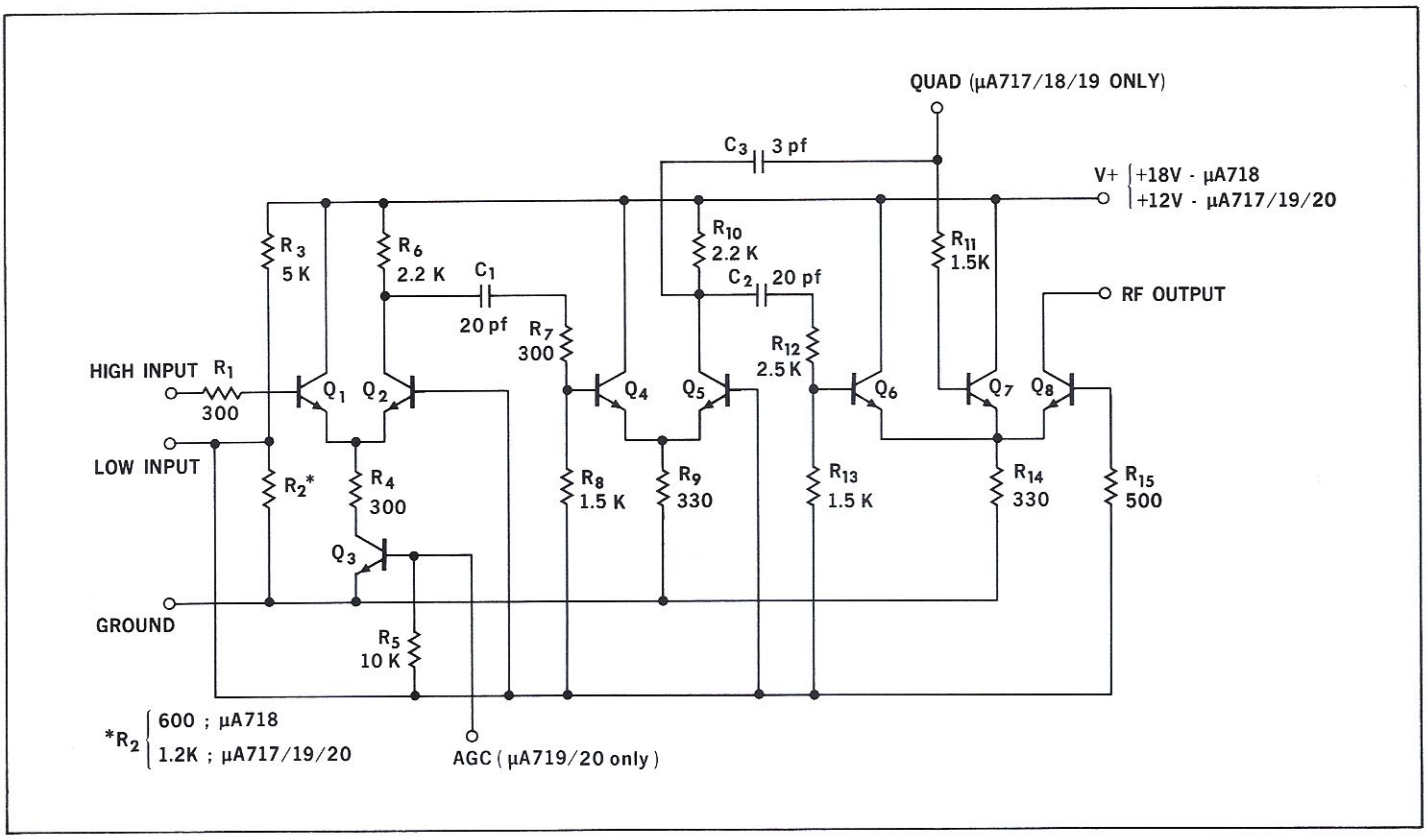

Fig. 3. Schematic of the RF sections of the μA717, μA718, μA719, and μA720 linear microcircuits.

Each of the three cascaded stages has a common biasing network consisting of the resistor divider, R_2 and R_3. By the use of an optional metal mask for the μA718, only one half of R_2 (600 ohms) is used, allowing 18-volt operation, with essentially the same current through all the transistors as with the μA717, μA719, and μA720 which operate from a nominal 12-volt supply. If voltages other than 12 or 18 volts are required, an external resistor connected in parallel with either R_2 or R_3 will allow operation with supply voltages from 6 to 18 volts.

AGC may be obtained by applying a positive differential voltage between the "HIGH INPUT" and "LOW INPUT" terminals, thus increasing the current in Q_1 and reducing the current in Q_2. However this method is usually inconvenient and transistor Q_3 is included for applying reverse AGC to transistors Q_1 and Q_2 simultaneously.

With no AGC, transistor Q_3 operates in collector-to-emitter saturation, having a saturation resistance of approximately 30 ohms. By drawing current from the AGC terminal, transistor Q_3 is first brought out of saturation and then used to reduce the current available to transistors Q_1 and Q_2. The advantage of this scheme is that, if no AGC is required (this being the case for TV-IF sound system and FM-only applications), then the AGC terminal need not be connected externally. This reduces package complexity and cost.

The second cascaded stage is similar to the first stage but of course has no AGC capability. Capacitor C_1 is chosen so that the low-frequency rolloff of the amplifier does not greatly degrade AM-IF operation (455 kHz), and at the same time does not occupy a large area on the chip.

The third stage may be used either as an FM quadrature detector or as an additional stage of gain, depending on the external circuitry used. This stage reduces to an amplifier if the QUAD terminal is either connected to the "GROUND" terminal or is left open-circuited. In either case, transistor Q_7 will be biased-off and the effect of the components C_3, R_{11}, and Q_7 will be negligible.

The mode of operation of the quadrature detector may best be understood by considering the digital function of a transistor emitter-coupled trio, namely the OR gate.

Figure 4 shows an OR gate having two input signals and one output signal. The output logic is shown in Table I. If

TABLE I.

Logic Table for an "OR" Gate Having Two Input Signals.

INPUT 1	INPUT 2	OUTPUT
High	Low	High
Low	High	High
High	High	High
Low	Low	Low

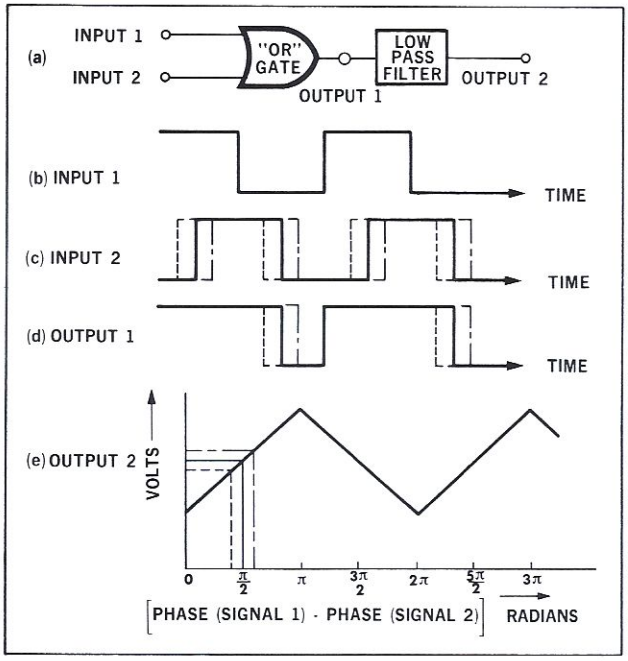

Fig. 4. The input and output waveforms of an "OR" gate.

either or both the input signals are "HIGH" (in our case, POSITIVE, with an amplitude of 0.7 volt peak-to-peak or more) the output signal is HIGH. If both input signals are "LOW", the output signal is LOW. The input and output signals are shown in Fig. 4b, 4c, and 4d, respectively, as time-varying functions. If the phase of INPUT 2 is displaced $\pi/2$ radians with respect to INPUT 1, the LOW period of the output signal will also be $\pi/2$ radians. Now if the phase difference between INPUT 1 and INPUT 2 is varied from $\pi/2$ radians, the LOW period of the output signal will also vary as a linear function of this phase difference. The output signal for the OR gate, when passed through a low pass-filter to remove the high frequency and switching components, leaves a DC level which also is a linear function of the phase difference between the two input signals (Fig. 4e). To convert the OR gate into an FM quadrature detector, it is necessary to provide a means of shifting the phase of the two input signals independent of frequency by $\pi/2$ radians, and then to provide a linear frequency-phase sensitive network to vary the phase difference of the two signals about $\pi/2$ radians.

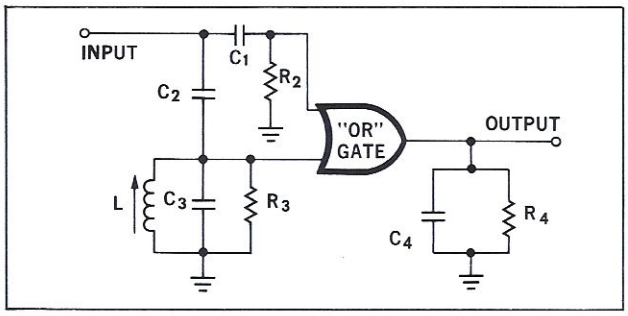

Fig. 5. Conversion of an "OR" gate into an FM quadrature detector.

Fig. 5 gives the basic phase-shifting components for a simple quadrature detector. Assuming that both C_1 and C_3 are much larger than C_2, then at the frequency

$$f_o = \frac{1}{2\pi\sqrt{LC_3}}$$

the phase of the voltage applied to the OR gate, INPUT 2 will be approximately $\pi/2$ radians in advance of INPUT 1 if: (1) the reactance of C_2 is much larger than R_3, and (2) the reactance of C_1 is smaller than R_2. If the frequency of the input signal is varied by a very small amount (this is the case for both TV sound and FM-IF signals) then the phase-frequency relationship between INPUT 1 and INPUT 2 will be approximately linear. The output signal from the OR gate can be integrated with R_4 and C_4 to remove the fundamental components of f_0 and the resulting switching components of f_0. At the same time, de-emphasis can be achieved by suitable choice of these components.

Referring to Fig. 3, it can be seen that by connecting a quadrature tank circuit consisting of a parallel capacitance and inductance between the QUAD and LOW INPUT terminals, a DC bias is established on the base of Q_7 similar in value to the bases of Q_6 to Q_5, thus assuring equal collector current in Q_6, Q_7, and Q_8 without an input signal. The phase of an input signal applied to the base of Q_7 will be approximately $\pi/2$ radians advanced with respect to the signal applied to the base of Q_6, with a suitable choice of quadrature tank component values. Also, the phase difference between these two signals will be frequency-dependent.

Figure 3, therefore, is functionally identical to the OR gate shown in Fig. 5. For clarity, the quadrature detector is redrawn in Fig. 6. The resistors R_{11} and R_{12} serve to isolate the common input drive point at the collector of Q_5 from switching transients fed back from the bases of Q_6 and Q_7.

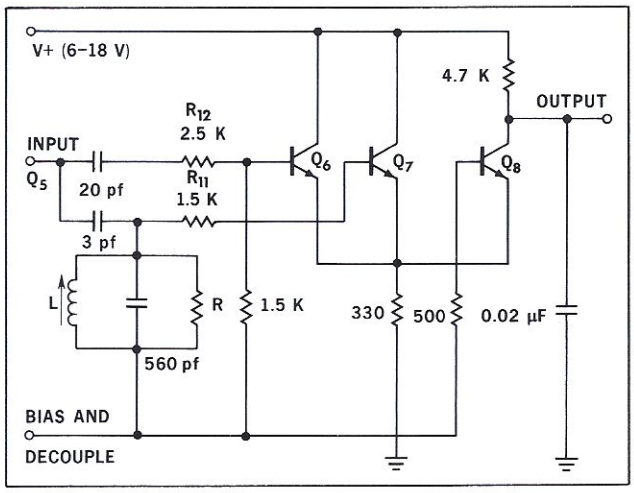

Fig. 6. Practical FM quadrature detector for operation at frequencies 1 to 20 MHz.

The third stage of the RF section of μA717 through μA720 series of microcircuits may be used as an additional audio preamplifier for FM-AM applications by employing the QUAD terminal as an audio input and taking the output signal from the collector of Q_8. [1]

Audio Sections

In addition to the RF section, the μA717 through μA720 microcircuits contain audio amplifiers capable of driving either tube or transistor audio output stages for television and FM-AM applications. Because the drive requirements for tube and transistor output stages differ, two audio amplifier circuits were found to be necessary. Fifteen volts or more peak-to-peak drive is necessary for an audio output tube; whereas, for a transistor output stage, the requirement is a high peak-to-peak current drive. The transistor audio-output drive requirements impose severe restrictions on the design of the preamplifier and drive circuitry. The design objectives for the amplifier include the following:

1. High output current and power gain capability.
2. An accurate DC bias provision for an audio output transistor.
3. Flexibility in changing the DC bias by circuitry.
4. Only two connections to the audio section of the microcircuit (input and output) for normal operation.
5. Protection of the output transistor against accidental short circuit to ground of the output terminal of the microcircuit.
6. Use of a suitable metal interconnection mask so that audio section of the microcircuit could drive a tube.

The two audio sections for the μA717 and the μA718 are given in Fig. 7. The biasing schemes for both audio sections rely on the close matching between similar monolithic components. The value of the collector current of Q_9 is approximately the supply voltage divided by R_{16}. As Q_9, Q_{10}, together with R_{18}, R_{19}, and R_{20}, R_{21}, are closely matched pairs of components, the collector current of Q_9 is identical to that of Q_{10}. [2] The collector voltage of Q_{10} is thus accurately established. For the μA717, this voltage is 4 volts and for the μA718, approximately 9 volts or one-half the supply voltage. It is necessary to limit the μA717 output voltage swing in the positive direction to about 6 volts, otherwise there is a possibility of damaging the audio output transistor. Q_{11}, R_{22}, and R_{23}, are used as a voltage limiter, allowing the output voltage swing at the emitter of Q_{12} to be approximately 5 volts peak-to-peak. Transistor Q_{12} provides the necessary drive current to the audio output transistor. R_{24} provides short circuit protection for Q_{12}, allowing the emitter of Q_{12} to be grounded for a short time without damage to the microcircuit.

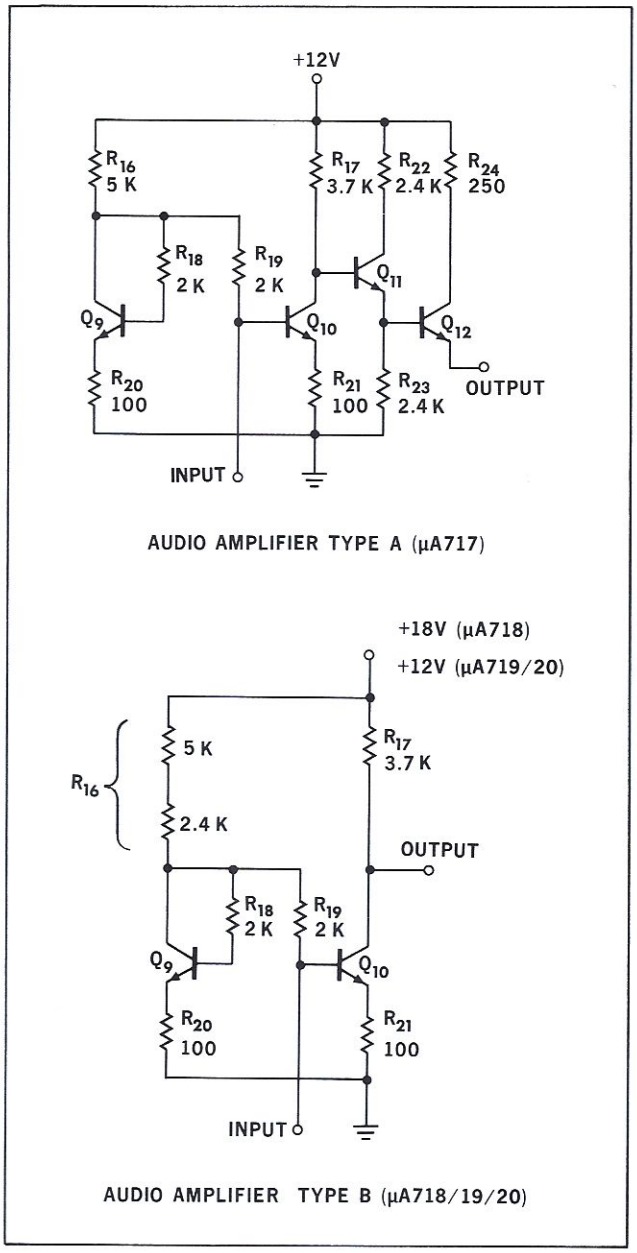

Fig. 7. Audio section of μA717, μA718, μA719, and μA720 linear microcircuits.

Applications

Figs. 8 and 9 provide two typical applications for the μA717 and the μA718. In Fig. 8, a complete TV sound system is shown for a hybrid TV receiver with the sound IF signal at 45 megahertz being taken from the video IF amplifier. The second application shows the μA718 in a high quality FM-IF strip. In this example, the audio section of the first μA718 is used as an additional 10.7-MHz amplifier. The four-pole filter is placed between the RF section and the audio section to reduce the signal level to the audio section. This avoids limiting in the audio section, which would degrade the capture ratio. The FM-IF strip employs a two-pole quadrature detector to improve the linearity. The recovered audio signal from the quadrature detector is amplified through

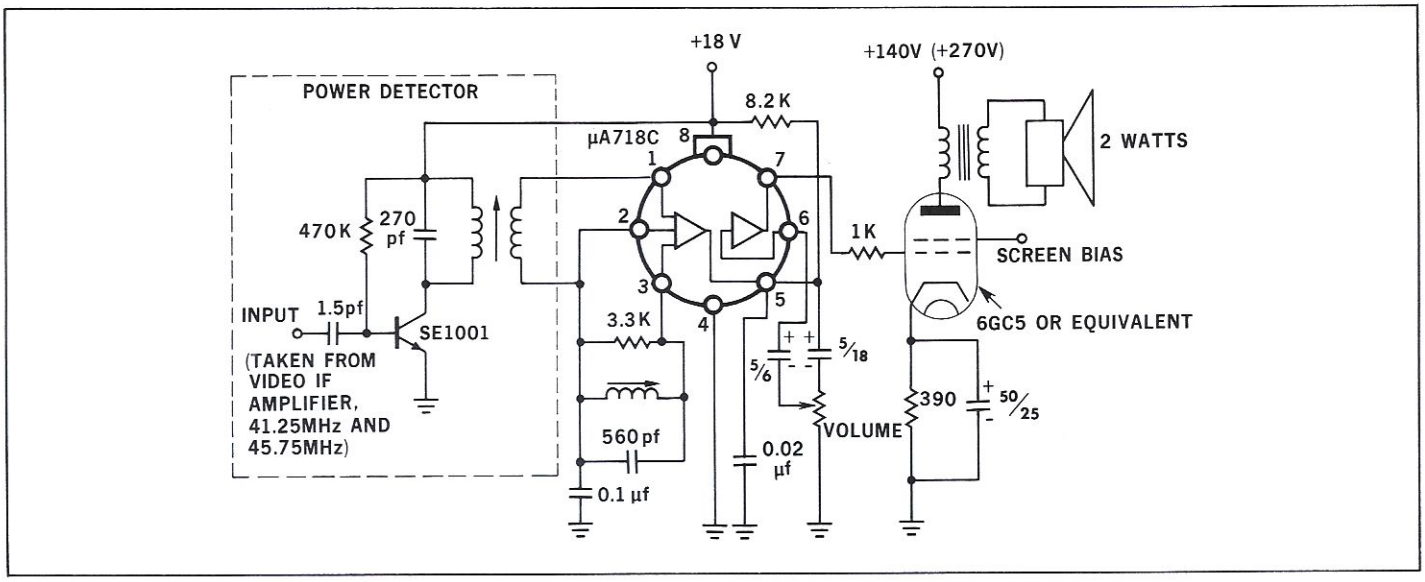

Fig. 8. Hybrid TV receiver sound system.

the audio section of the second μA718. Specifications for this amplifier are:

Sensitivity: 3 dB limiting	$<5\mu V$
Capture ratio (1000 μV input)	1.5 dB
THD (400 Hz, 100% MOD)	<1%
Audio output voltage (400 Hz 100% MOD)	3 volts peak-to-peak

SUMMARY OF DESIGN CONSIDERATIONS FOR THE μA717 THROUGH μA720

Electrical

The circuit configurations used in the μA717 through μA720 series of microcircuits have been designed to exploit the unique characteristics of monolithic components. In the RF section, a minimum number of isolation areas has been

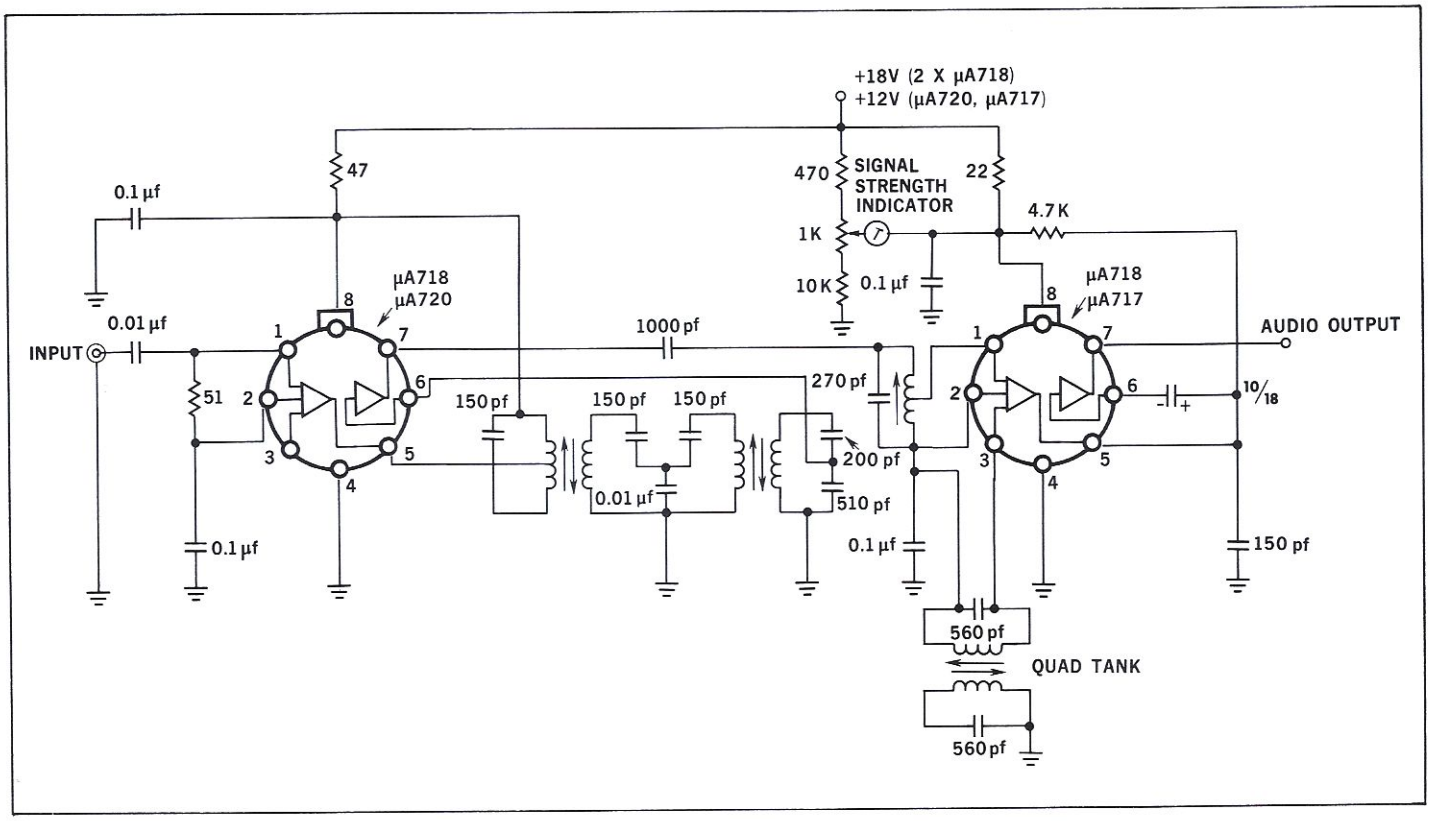

Fig. 9. High-quality FM-IF strip.

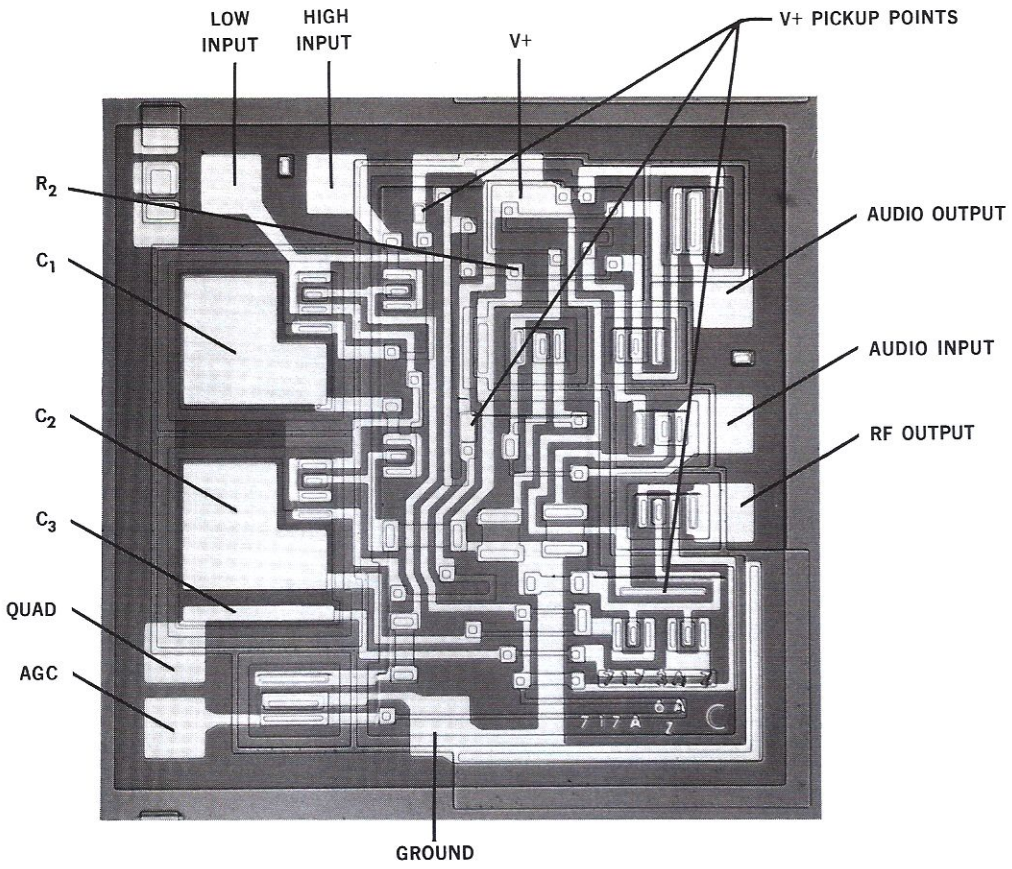

Fig. 10. Photomicrograph of the μA717 chip.

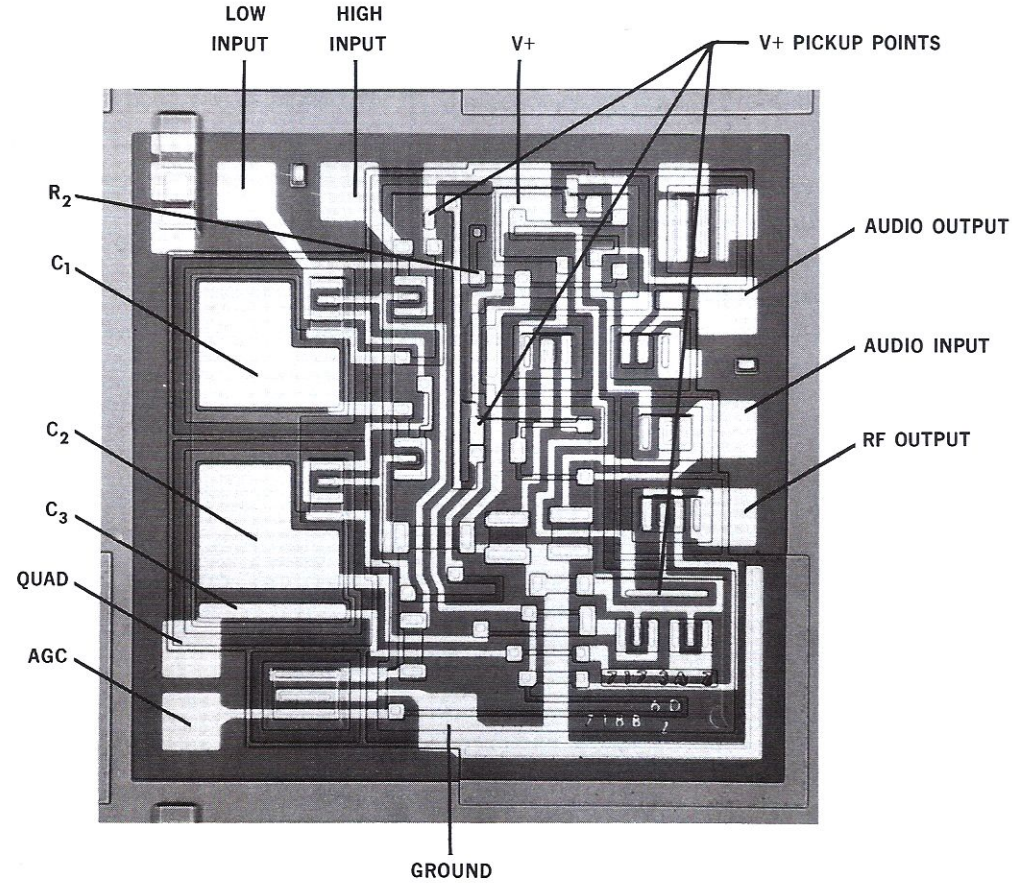

Fig. 11. Photomicrograph of the μA718 chip.

achieved by using cascaded stages of emitter-coupled transistors. The DC voltages at all points in the RF section depend principally on the matching of components. For example: the common bias point relies on close matching of the ratio of R_2 and R_3; the voltage of the collectors of Q_2 and Q_5 rely on the ratios of resistors R_4, R_6, and R_9, R_{10}, together with the matching of the parameters of the transistor pairs Q_1, Q_2 and Q_4, Q_5.

The audio sections use a well known biasing scheme[2] which relies almost solely on the matching of components and not on their absolute values.

Physical Considerations

Figs. 10 and 11 are microphotographs of the μA717 and μA718 chips. For successful realization of the high stable gain, certain layout procedures are observed:

1. The HIGH INPUT terminal is positioned diagonally opposite the RF OUTPUT.

2. The large isolation area containing the resistors and emitter-followers isolates the input stages of the RF section from both the output stage and the audio section. It should be noted that this isolation area is connected to the V^+ and is therefore AC grounded.

3. Common current-sharing paths in the metal interconnections are minimized to reduce cross talk between various sections of the microcircuits. Note that there are five separate paths to the V^+ pad, also that there are three V^+ pickup points to the large center isolation region.

The layout of a microcircuit is in many ways similar to a conventional discrete circuit; good ground, shielding, and minimum metal connection lead lengths are necessary. In contrast to most discrete circuit layouts, wasting space on an IC chip is expensive. Therefore, it is important to achieve maximum component density and to use the minimum number of components and external connections for a maximum number of possible circuit functions.

CONCLUSION

The μA717 through μA720 series of microcircuits demonstrates the possibility of using basic IC chips, and by choosing various metal interconnection patterns and packages, producing devices with optimum orientation for various TV, FM, and FM-AM applications. These objectives are achieved with minimum manufacturing costs and redundancy.

REFERENCES

1. David Bingham and Ted Hanna, "A Low-Cost FM-AM Table Radio Employing an Integrated Circuit", IEEE Transactions on Broadcast and Receivers; July 1967.
2. R. J. Widlar, "Some Circuit Design Techniques for Linear Integrated Circuits", Fairchild Semiconductor Technical Paper 33; January 1966.

APPENDIX

Salient features of the μA717 through μA720 series of microcircuits are depicted in Table II.

TABLE II.
Features of μA717 - μA720 Devices.

DEVICE	μA717E	μA718C	μA719	μA720E
Package	TO-5 epoxy 8 leads	TO-5 metal 8 leads	TO-5 metal 10 leads	TO-5 epoxy 8 leads
Nominal supply voltage	12 V	18 V	12 V	12 V
QUAD	Yes	Yes	Yes	No
AGC	No	No	Yes	Yes
R_2	1.2 kohms	600 ohms	1.2 kohms	1.2 kohms
Audio Section (See Fig. 7)	A	B	B	B